TOWARDS A MULTI-LEVEL MODELING APPROACH FOR RECONSTRUCTION APPLICATION TO MEDICAL DATA

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Abstract - **This paper introduces a new modeling approach we call multi-level, which is well adapted to smooth objects coming from medical data. We believe in the importance of taking into account the global and the local characterization of an object, within a single model. Our model takes advantage of implicit surfaces with skeletons to represent the shape globally. Successive implicit layers then refine the model, in order to describe each level of detail in a coherent way, until the finest level, which corresponds to small local variations of the shape. We also present an original reconstruction method based on this model. Finally an application to the vertebra is presented.**
Keywords - **3D medical imaging, multi-level modeling, reconstruction, implicit surfaces, digital volumes, skeleton**

I. INTRODUCTION

A. Motivations

Medical data are larger and larger, more and more complex, and we have to find new ways to characterize them. This brings out the notion of modeling in computer graphics, which is fundamental for organ imaging. In the case of simple shapes, modeling is not an obstacle, however we can think about the way we represent the shape. The underlying notion is shape description. It is all the more difficult to implement as the shape to model presents a high level of detail, such as human organs.

In this paper, we focus on closed surfaces, and the volumes related to them. Our aim is to synthesize the structure of objects whose geometry is not precisely defined or whose shape can vary.

We exclude parametric representations because these representations need to set an *a priori* which is too important on the shape to model. The other reason is that this sort of representation is mainly dedicated to the *local* control of the surface. It is difficult to apprehend a shape defined parametrically on a global scale. And this is actually a point we find important for our model.

It is for these reasons we choose to work on an approach of modeling by implicit surfaces, particularly by surfaces with skeletons [1,2,3,4]. The latter allow a global intrinsic control of the shape based on an entity, the skeleton, globally centered in the object. Contrary to parametric surfaces, we can't place ourselves on an implicit surface. We can only know whether we are inside or outside of the volume generated by the surface, or on the surface itself. The main asset of this type of surface is that we set no topological *a priori* on the shape to model, the structural information coming directly from the skeleton.

However, the approach by implicit surfaces can be disadvantageous when we wish to have an efficient local control. To model small variations on the surface, regardless of the global shape of the object, the surface-generating skeleton has to be extremely well detailed. This induces a very high number of primitives, and leads to an explosion of the complexity during a simple rendering of the surface. We are then led to the limits of the rough approach by skeleton: a simple skeleton allows us to model simple shapes, but for complex shapes, the skeleton has to be very ponderous. We are then faced with several problems, particularly in an applicative reconstruction context. Moreover, if we use a skeleton directly extracted from data (in a reconstruction frame), it is to note that the skeleton is very unstable because it is sensitive to very small variations: we lose the global aspect of the shape descriptor.

We then naturally went towards a *multi-level* modeling approach by implicit surfaces with skeletons. Our idea is that if we work in low resolution, we have a *global* apprehension of the shape. To complement, consecutive layers allow us to refine the model by gradually increasing the resolution level and then obtaining a higher level of detail.

This article is divided in three parts. The first part presents our multi-level model by implicit surfaces, based on a structural information by layers. Then we describe the reconstruction process of 3D objects in the second part, and finally we apply this approach to medical data, the objects being represented as digital volumes.

II. MULTI-LEVEL MODEL

A. Implicit surfaces defined by skeleton and potential function

Before focusing on the model itself, let's go through several notions and definitions. Implicit surfaces defined by skeleton and potential function are characterized by a set of geometrical primitives (the skeleton, in other words the *seeds*, which here are points) and a potential function, depending on the distance between points and seeds [5]. For a skeleton composed of γ_k seeds, the corresponding surface is the isosurface (The constant *iso* represents the isopotential for which the points are *on* the surface.):

$$S_k = \{P / F_k(d(P,\gamma_k)) = iso\}$$

The implicit surface *S* is the isosurface defined by the sum (the *blending*) of the contributions of local potentials F_k applied to the N_γ seeds of the skeleton, with the aim of

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Abstract

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smoothing the junctions' zones and ensuring the geometric continuity of the surface.

The global potential function is:

$$F(P)=\sum_{k}^{N_T} F_k(P)$$

The global surface related is the following isosurface, for the constant *iso*:

$$S=\{P / F(P)=iso\}$$

The skeleton underlying the surface is a cloud of weighed points. Each point contains a value used for the generation of the related surface. This value is divided by 2 when we move from an intern layer to the next layer of the multi-level model.

Numerous potential functions are dedicated to implicit surfaces. They depend on the Euclidean distance of a point in space to a primitive. We use *alpha-functions* [6] (see Fig. 1), generated by three parameters *r*, *R*, *k* (to refine blending and potential influence problems) and that have bounded support (to avoid useless and expensive calculus beyond the influence radius).

This function is defined by two pieces of exponentials, relative to another parameter α , itself in terms of *r*, *R* and *k*.

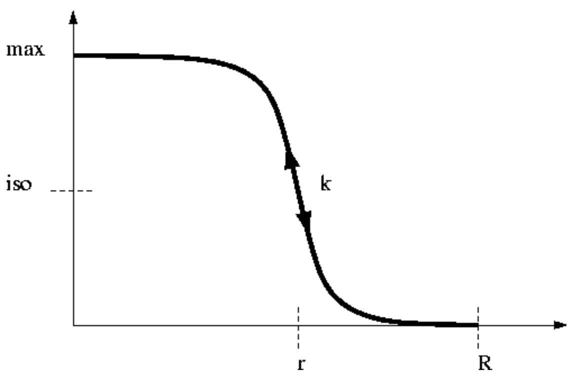

Fig. 1. The potential function.

B. Definition of the model

Let N_0 be the roughest level of detail. The corresponding shape is implicitly generated by included seeds in the volume and the potential function with three parameters we defined earlier. Let (r_0, R_0, k_0) be the parameters related to each primitive. We consider the generating points to be included in a cubic grid n_0^3 .

The following detail layer (the N_1 level) is defined in a grid twice as thin $n_1^3=(2n_0)^3$ (for the generating seeds' coordinates). The corresponding parameters are $(r_1=r_0/2, R_1=R_0/2, k_1)$, k_1 being set so that the surfaces of which the primitives are connected, are linked. Thus, we have the parameters $(r_i=r_0/2^i, R_i=R_0/2^i, k_i)$ for the level N_i .

Our model is composed of several levels that characterize the transitions between the global shape and the surface's local variations. The more the current layer corresponds to a high level of detail, the more the skeleton's primitives, generating implicit surfaces, are small (that means that the radius of an implicit primitive decreases when the level of detail increases).

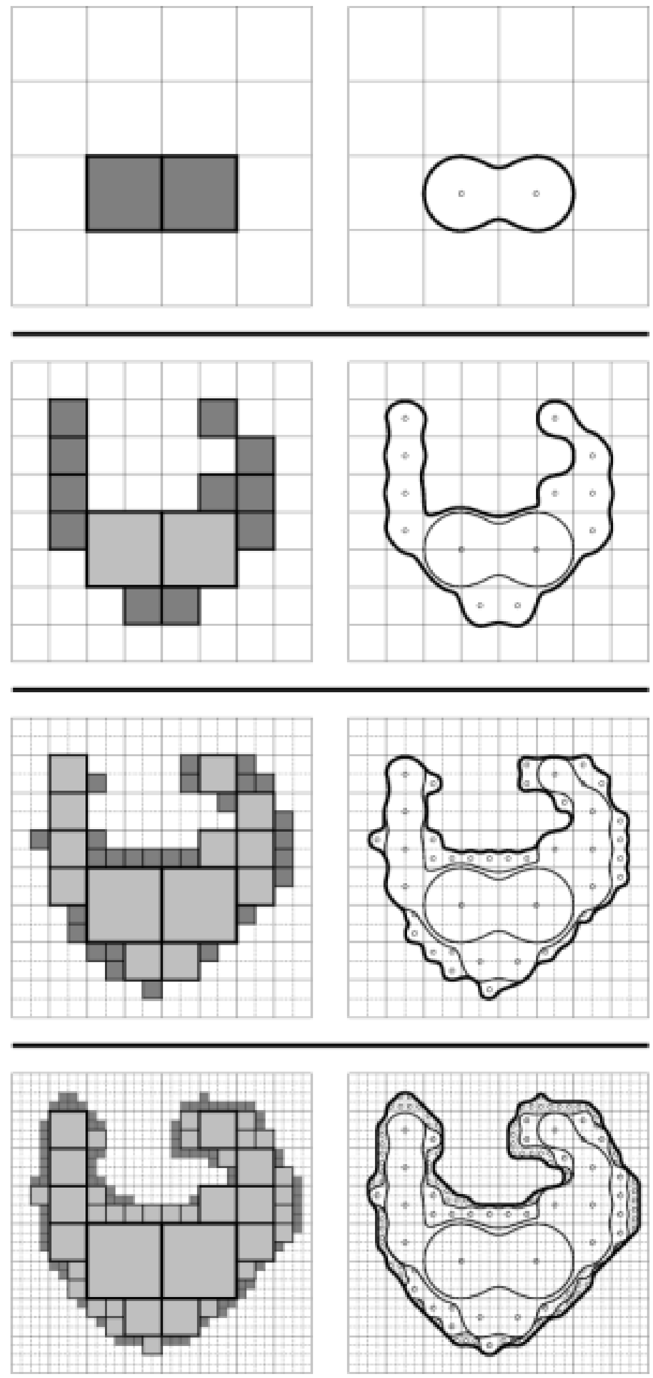

Fig. 2. The layers of an object's model.

Contrary to other multi-scale approaches where the level of detail is set by a threshold for the radiuses of the implicit primitives to represent (the latter are then scattered without structure in the volume), we place the *largest* generating seeds in the center of the object. We don't try to maximize their radiuses to come very close to the surface to model (concept of *maximal balls*), which gives us coherent global characterization from the very first step (in terms of shape descriptor). The volumes related to the seeds are strictly included into the shape.

Then come the layers of smaller seeds for the next levels of detail, which successively *surround* the first shape. The implicit *blending* definition allows us to compact the shape. The volumes are still included into the shape. The last level corresponds to a primitive layer of the order of one voxel (depending on the resolution chosen), to complete the model on an exclusive local plane (Fig. 2).

The term *shape descriptor* doesn't mean that we represent the general morphology of the object in a usual way. Here, we talk about a description of the characteristic shapes of the object, in order of importance according to the level we consider. The first levels represent the shape in a rough way, some characteristic shapes starting to appear. The last levels represent the details, the small variations at the surface of the object: they only have a sense for a very precise geometrical characterization.

III. The Reconstruction Process

We apply our multi-level modeling approach to the reconstruction of 3D objects, represented for our study by digital volumes.

Let n be the number of voxels corresponding to the edge of a cubic digital volume. We call V_n this starting volume. It represents the discrete object with maximal resolution. The sub-resolution related to V_n is calculated by embedding in a cubic grid $(n/2)^3$ and by considering the digital volume $V_{n/2}$ strictly included in V_n. The voxels then have edges with a length of 2. $V_{n/2}$ is the discrete characterization of V_n by sub-resolution. The next sub-resolutions $V_{n/2^i}$ are successively calculated using the $V_{n/2^{i-1}}$ by embedding them in $(n/2^i)^3$ grids and by applying strict inclusions, until the step preceding the null volume.

Let $V_{n/2^k}$ be that minimal resolution digital volume, after k steps of sub-resolution. The volume consists in few voxels, each having edges of length $2k$ according to the original volume V_n. The first level of reconstruction, minimal, is the implicit surface generated by the *medial axis* (the set of the maximal balls included in the object) of the volume $V_{n/2^k}$, which then constitutes $A_{n/2^k}$: the level 0 skeleton of the object. When the volume consists in few points, the medial axis is almost merged with the volume itself, but its points are then weighed and give good initializing values of the surface. For the following layers, medial axis extraction can reduce the number of primitives describing the model.

The volumes' skeletons, corresponding to higher levels of detail are calculated, not by extracting the medial axis of $V_{n/2^i}$, but of the $V_{n/2^{i-1}} - V_{n/2^i}$ differences, because we still have $V_{n/2^i} \subset V_{n/2^{i-1}}$. We really have a *multi-level* approach: for a given level, the surface is the blending of a kernel and several implicit *layers.*

After each step, the implicit surface bases itself on the $A_{n/2^i}$ skeleton to reconstruct the *crust* points (the *boundary*) of the original digital volume V_n. We then enter a classical reconstruction process of a cloud of points by implicit surfaces [4].

In a first step, the parameters (r,R,k) of each seed are initialized in a coherent way considering the $2i$ size of the voxels of the grid at stake and also considering the values of the maximal balls' radiuses associated to the seeds. The more the skeleton corresponds to deep layers of voxels, the more the related implicit primitives are large. The last layer, corresponding to the A_n skeleton, represents small variations, of the order of a one-size voxel (of the original volume V_n).

IV. Application to Medical Data

Fig. 3, 4 and 5 show the process for the digital volume of a *vertebra* coming from real data. We can see characteristic shapes appear at each step, the more the level of detail is high.

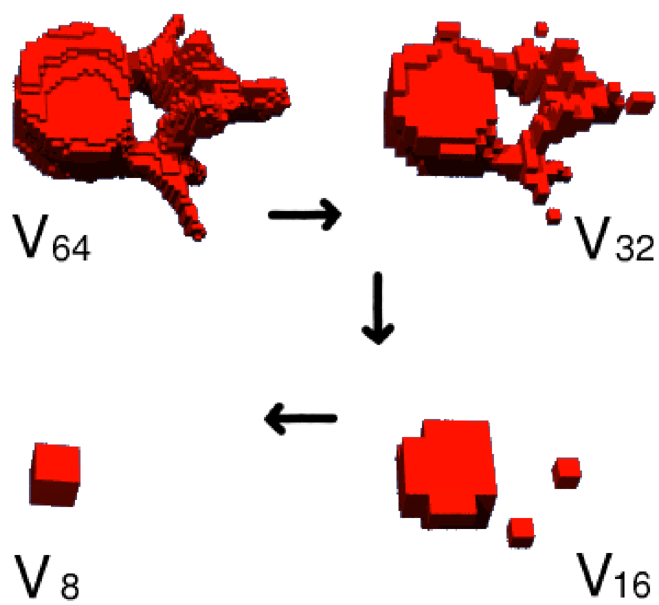

Fig. 3. V_{64} , the original digital volume, and its related sub-resolutions V_{32} , V_{16} and V_8 .

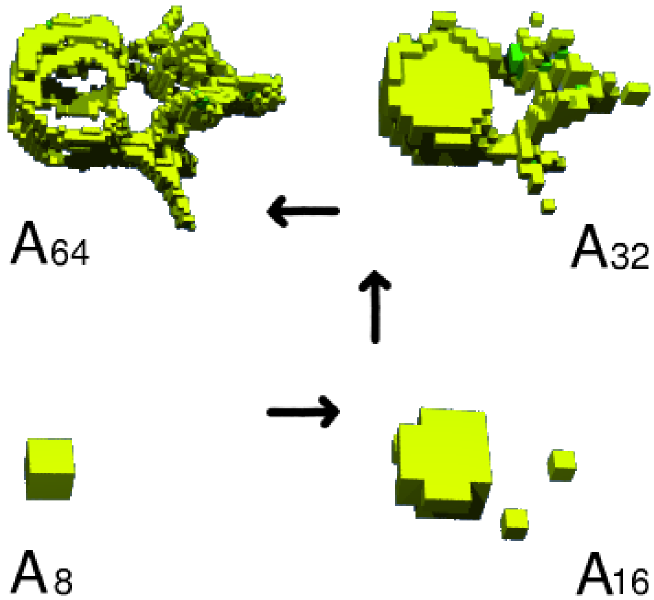

Fig. 4. Skeleton-layers related to differences between volumes.

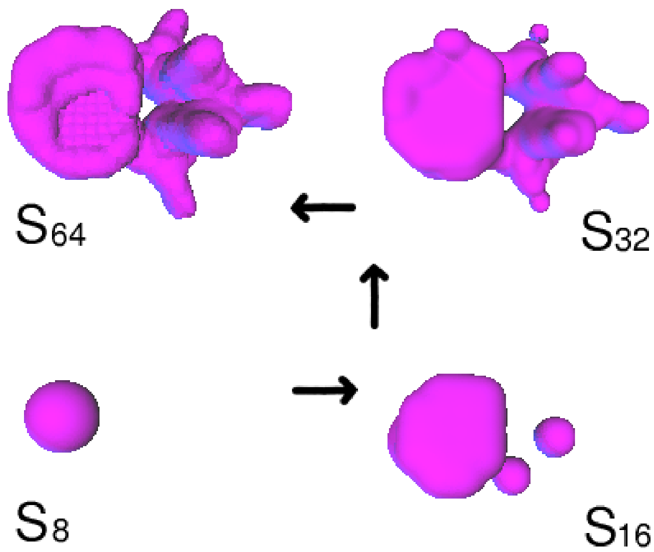

Fig. 5. Multi-level reconstructions by implicit surfaces.

Because of its simplistic nature, this approach lends itself well to the reconstruction of bulky objects with complex topology, such as organs in medical imaging. The shape descriptor is easily adapted according to the needs or the computer's performances.

V. Conclusion

In this paper, we came up with the idea of a new model: a multi-level model. The principle is to start off with a kernel defined by an implicit surface, on which we superpose layers of the same type. Thanks to the definition by blending, the layers, when they are compacted, allow us to constitute the shape to model.

This model is well adapted to reconstruction problems, and in particular to smooth surfaces, such as organs in medical imaging. The multi-level approach induces a coherent and natural reduction of the number of primitives. The time spent for the first levels of reconstruction is quite short, because of the low number of seeds.

At this stage of the model’s elaboration, the prospects are:

1) First of all, we could establish a mesh on the seeds of each layer, to control the model's topology explicitly. This would imply, for example, the implementation of a selective blending for the implicit surfaces generated, in order to prevent *unwanted blendings*;

2) A reflection on the way to deal with transitions between the layers. At the present time, the layers surround each other and combine by implicit blending, but we could establish a structure between these layers that would be more coherent.

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References

[1] S. Muraki. Volumetric shape description of range data using “blobby model”. *Computer Graphics (Proceedings of SIGGRAPH’91)*, vol. 25(4), pp. 227-235, 1991.

[2] V.V. Savchenko, A.A. Pasko, O.G. Okunef and T.L. Kunii. Function representation of solids reconstructed from scattered surface points and contours. *Eurographics’95*, 1995.

[3] E. Bittar, M.-P. Cani Gascuel and D. Attali. Skeletal reconstruction of branching shapes. *Implicit Surfaces’96*, pp. 127-142, 1996.

[4] J.-L. Mari and J. Sequeira. Using implicit surfaces to characterize shapes within digital volumes. *RECPAD 2000 Proceedings*, pp. 285-289, Porto, Portugal, May 2000.

[5] J. Bloomental, C. Bajaj, J. Blinn, M.-P. Cani-Gascuel, A. Rockwood, B. Wyvill and G. Wyvill. *Introduction to implicit surfaces*. Computer Graphics and Geometric Modeling. Morgan Kaufmann, 1997.

[6] C. Guiard. Modèles de surfaces déformables définis et contraints par un ensemble d’informations structurelles. PhD Thesis. Université de la Méditerranée – Aix-Marseille II, 2000.